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ABSTRACT

This paper is a summary of much of the available research on college science laboratory instruction of the past decade with a focus on the effects of specific laboratory teaching strategies upon student learning outcomes. Some tentative interpretations from a review of the literature found are: (1) inquiry or investigative approaches in college laboratory science courses appear to be generally productive (newer, innovative approaches resulted in more students involved the greater use of inductive, and process skills); (2) students can be taught to improve their use of formal operational thought by the use of concrete, manipulative laboratory experiences (the more direct the student involvement in laboratory, the more the student appears to learn); (3) computer-based applications in the laboratory are of great interest to college science faculty and in some cases have been shown to be as or more productive than conventional methods; and (4) productive laboratory instruction appears to have students engaged in inquiry processes, in manipulation of experimental apparatus, and by teaching simultaneously, science process skills and science concepts. (MVL)

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A REVIEW OF RESEARCH ON SCIENCE LABORATORY INSTRUCTION AT THE COLLEGE LEVEL

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A B S T R A C T

This paper is a summary of much of the available research on college science laboratory instruction of the past decade with a focus on the effects of specific laboratory teaching strategies upon student learning outcomes.

A literature search was conducted on the topic of laboratory science instruction at the college and university level. All issues of the Journal of Research in Science Teaching, Science Education, American Educational Research Journal, Review of Educational Research, Journal of College Science Teaching and Abstracts from the annual meetings of the National Association for Research in Science Teaching since 1978 were hand searched for relevant articles. A computer search on the topic was also done from the ERIC data base. Thirty six relevant research articles were found and appeared to be grouped in the following areas: (1) inquiry or investigative laboratory strategies, (2) the development of reasoning and problem solving skills, (3) computer-based applications, and (4) other miscellaneous studies.

Some tentative interpretations from a review of the literature found are: (1) Inquiry or investigative approaches in college laboratory science courses appear to be generally productive. Newer and more innovative approaches over the past ten years were more student-involved, were more inductive and required more extensive use of science process skills. They generally produced significantly greater educational gains than the more traditional approaches. Nevertheless, the experimental novelty effect will continue to be suspected. (2) There is some evidence that students can be taught to improve their use of formal operational thought through the use of concrete, manipulative laboratory experiences. Some students designated as concrete thinkers can develop an understanding of concepts considered to require formal thought if given appropriate laboratory experiences. The more direct student involvement in all aspects of the laboratory activity, the more the student appears to learn. (3) Computer-based applications in the laboratory are of great interest to college science faculty and have, in some cases, shown to be as productive or more productive than the conventional laboratory exercise. Much more activity in both development and research of this technology is expected. (4) Productive laboratory instruction in college science courses appears to be distinguished by having students engaged in science inquiry processes, by having the student engaged in the manipulation of experimental apparatus, and by teaching, simultaneously, science process skills and science concepts. More research on laboratory instruction in college-level science courses should be encouraged.

A REVIEW OF RESEARCH ON SCIENCE LABORATORY INSTRUCTION AT THE COLLEGE LEVEL

Purpose of the Study

Only a decade ago, one would have found very little in the educational research literature on college-level laboratory instruction in the sciences. The few studies which were reported investigated primarily the value of laboratory instruction rather than specific approaches to laboratory instruction. Most compared laboratory to non-laboratory approaches or inductive to deductive laboratory approaches. Many of these studies had questionable experimental integrity; so it is no surprise that the sum of them produced conflicting and confusing results. The fact that the vast majority of college science courses now contain a laboratory component suggests that faculty do see an inherent value to laboratory instruction. During the past decade, there has been much more research on college laboratory instruction and the research has focused on specific laboratory teaching strategies and learning outcomes. The following is a summary of much of the available research on college science laboratory instruction of the past decade, grouped by some of the dominant areas being investigated.

Method

A literature search was conducted on the topic of laboratory science instruction at the college and university level. All issues of the Journal of Research in Science Teaching, Science Education, American Educational Research Journal, Review of Educational Research, the Journal of College Science Teaching and Abstracts from the annual meetings of the National Association for Research in Science Teaching since 1978 were hand searched for relevant articles. A computer search on the topic was also done using the ERIC data base. The resulting review was organized by what appeared to be the following areas of research focus in the literature: (1) inquiry or investigative laboratory strategies, (2) the development of reasoning and problem solving skills, (3) computer-based applications, and (4) other miscellaneous studies.

Results: A Summary of the Literature Search

In the late 1970s, Kyle and others (1979) observed that college students in most introductory science courses in a large midwestern university were performing cookbook-like laboratories and were not learning the process skills of science; students spent a significant amount of laboratory time listening to the instructor simply transmit information. Stewart (1988) observed that most standard laboratory experiments in introductory college science courses contain a set of directions to be followed explicitly if the experiment is to generate usable data. Fogle (1985), arguing for investigative laboratory strategies, noted that introductory college students do not understand the nature of scientific questioning; misuse of the terms hypothesis, fact, and theory is symptomatic of student misconceptions.

Since the above observations were made, a number of studies attempted to develop and test alternative approaches to the more traditional laboratory investigation. Most of the innovative approaches were modifications of the inquiry model and employed discovery or inductive approaches to learning. In one such study elementary education majors taking a required course in science and mathematics were instructed with two contrasting laboratory methods. One method was inductive inquiry based on direct interaction with concrete

materials and emphasis upon science process skills; the other was didactic, emphasizing the validation and application of previously stated concepts or principles. There were no significant differences between the two treatment groups (Blake, 1987). Splickler (1984) did a similar study in which concrete, manipulative laboratory experiences to learn about physical science produced greater achievement on some of the concepts, a greater comprehension of all areas taught, and better attitudes toward science than a similar class taught without the manipulative laboratory experience.

Several inquiry-based studies were done with the introductory biology laboratory. Training in integrated science process skill development was found to improve performance in using integrated science process skills among college biology students (Walkosz and Yeany, 1984). A Biological Sciences Curriculum Study (BSCS) inquiry approach was designed for a large sized university general biology laboratory program and tested experimentally for an entire semester against a well-established commercial program which was judged to be highly directive. Students using the BSCS-style approach scored similarly to those using the commercial approach on a pretest of selected biology laboratory concepts, but scored significantly higher when it was given as a posttest at the end of the semester (Leonard, 1986). The essence of this study was later replicated with students at two, small, private colleges and again, the group using the BSCS-style approach scored significantly higher on a test of laboratory concepts at the end of the semester (Hall and McCurdy 1988). Finally, an extended discretion laboratory approach, where students were required to determine their own investigatory procedures and strategies, was tested experimentally against a more directive laboratory approach in university general biology for a semester. Even though the former approach placed many more demands on student creativity and decision making, there were no significant differences on achievement measures between the two groups of students (Leonard, 1984).

Some very interesting work on the development of reasoning and problem solving abilities has been inspired by the theories of developmental psychologists such as Jean Piaget. Lawson (1980) has argued that many major concepts typically taught in introductory science courses require formal operational thought to be understood. He found that approximately one-half of students in college introductory biology are not fully formal operational, and these students were found not to be able to develop appreciable understanding of these abstract concepts. Fields (1985) found that typical, traditional (cookbook) laboratory exercises did little to foster the understanding of abstract concepts. There is evidence that students can be taught to improve their use of formal operational thought. Inquiry-based, hands-on approaches in general biology laboratory courses in which a series of laboratory investigations to teach formal reasoning formed the major mode of instruction were found to improve significantly the ability of students to use formal operational thought (Lawson and Snitgen, 1982; Journet et al, 1987).

Lawrenz (1985) found that grouping students in a physical science laboratory class for elementary education majors by similar cognitive ability was more effective in terms of their achievement than other alternative forms of grouping. Intensive instruction on cue attendance was found to increase significantly the problem solving abilities of science methods students, especially those skills related to developing and testing hypotheses (Wright, 1988). Very diverse populations of college students have been taught strategies to use formal reasoning in their science courses (Morgan et al,

1987). It is believed that, in order to teach concrete or transitional thinkers formal operational concepts, they need first to work with the principle in concrete terms, especially with manipulative activities provided in a laboratory environment. The students can then be supplied with symbolic representations of the principles so that the principles can be progressively internalized by gradually reducing the need for perceptual and motor supports. This provides students an opportunity to gradually abstract the principle from its concrete exemplars (Lawson and Wollman, 1975; Lawson, 1985).

There is a rich literature of studies using traditional computer-assisted instruction (CAI) in college science instruction, but only a few reports of use in conjunction with laboratory instruction, specifically. There appears to be much more in the literature of work done with computers linked to other technologies such as the videodisc player or laboratory instrumentation. In one of the former, students in an introductory chemistry laboratory course who used computer simulated experiments for four different laboratory topics did as well or significantly better than students performing the traditional laboratory investigation on the same topic. The CAI group also spent significantly less time learning the material (Calvin and Lasgowski, 1987). Curtis (1986) found a software system using modern data analysis techniques to help students with low and low-average mathematical skills more than it did students with high skills. Miller (1986) found no differences in achievement or attitudes due to student use of CAI materials in a community college biology laboratory course.

Microcomputers interfaced with laser videodisc players have provided a combination of the advantages of the microcomputer and traditional television or video images (Leonard, 1987). In a comparison of interactive videodisc versus the traditional laboratory to teach physical principles, no difference was found on pretest/posttest gains between the two groups of student (Waugh, 1987) found chemistry students using a laboratory simulation with an interactive videodisc system to score significantly better on both laboratory quizzes and on their laboratory reports than students using a traditional laboratory approach. Similarly, a large group of non-major biology students were assigned to either traditional laboratory exercises or simulations on an interactive videodisc system to learn about cellular respiration and about biogeography. Results showed no statistically significant differences between the groups on laboratory quizzes, laboratory reports, or a laboratory final exam. Opinion data on a questionaire indicated that students felt the videodisc instruction to give them more experimental and procedural options and more efficient use of instructional time than did conventional laboratory instruction and otherwise to be equivalent to the conventional laboratory. It was suggested that the interactive videodisc can, in some cases, provide comparable instruction to the wet laboratory (Leonard, 1987b and 1988a).

A recent development in laboratory instruction is the interfacing of laboratory measurement devices to a microcomputer. Examples of how to do this are given in physiology (Nicklin, 1985; Rhodes, 1986; Morgan et al, 1987) and in the physical sciences (Vernier, 1987). Some specific educational benefits of interfacing have also been identified (Leonard, 1988b). There have been no experimental research studies of interfacing to date.

Other Laboratory Teaching Studies

There have been studies in the past decade which are unrelated to those

in the above three categories. Both a lecture with laboratory and a lecture with a recitation organizational format for introductory biology produced greater student achievement than did a lecture only format. It was suggested that added active involvement, whatever the form, may have been the positive causitive factor (Saunders & Dickinson, 1979). Mental practice (where students were to told to imagine performing the laboratory tasks) was found to be as effective as physical practice (where students actually performed the laboratory tasks) in the achievement of chemistry laboratory skills (Beasley 1979 & 1985). Elements of instructional design such as explicitly stated objectives, reviews, examples, questions, and feedback (high structure) incorporated into a laboratory manual improved performance on a unit about kinetics in a physics laboratory course. Students receiving the additional structure scored higher on a quiz, took less time to solve laboratory problems, and felt more satisfied with the instruction provided. There were no differences between groups over their comfort with the knowledge acquired (Kozma, 1982). A field-oriented, on-site, instructional approach to geology was found to produce significantly greater interest and enjoyment than a traditional laboratory approach but neither approach produced any measured differences in concept learning (Kern and Carpenter, 1984).

Microbiology students using a modified laboratory schedule of meeting twice a week for one and a half hours were found to spend more time in the laboratory, made fewer procedural errors, fewer data errors, and had higher mean laboratory scores than an equivalent group of students who met for the traditional three hours per week (Firstman, 1984). A 45-minute prelaboratory preparation period given one or two days prior to the laboratory session in introductory chemistry was found to significantly improve student scores on both laboratory reports and laboratory examinations (Isom, 1985). The interview was found to be effective in revealing students' pre-and post-laboratory misconceptions and the misconceptions about molecular genetics were found to decrease substantially after students had laboratory experience (Koch, 1986). Individualized, autotutorial laboratory was found to produce significantly less student attrition and higher course grades than traditional group laboratory in introductory biology (Case, 1980). The laboratory associated with a learning center approach for college geology was found to have a significantly greater effect on students' short-term learning than did a more conventional laboratory approach (Tofte, 1982).

Conclusions

Inquiry or investigative approaches in college laboratory science courses appear to be generally productive. Newer and more innovative approaches over the past ten years were more student-involved, were more inductive and required more extensive use of science process skills. They generally produced significantly greater educational gains than the more traditional approaches. Nevertheless, the experimental novelty effect will continue to be suspected. There is some evidence that students can be taught to improve their use of formal operational thought through the use of concrete, manipulative laboratory experiences. Some students designated as concrete thinkers can develop an understanding of concepts considered to require formal thought if given appropriate laboratory experiences. The more direct student involvement in all aspects of the laboratory activity, the more the student appears to learn. Computer-based applications in the laboratory are of great interest to college science faculty and have, in some cases, shown to be as productive or more productive than the conventional laboratory exercise.

Meaningful science laboratory instruction at the college level appears to be distinguished in at least three ways. First, the student is engaged in a number of the science inquiry processes. Second, the student has the opportunity to manipulate experimental apparatus in order to provide a "hands-on" experience. Third, the student is simultaneously taught science process skills and science concepts in a very experiential manner. More research on laboratory instruction in college-level science courses should be encouraged.

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